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(54) Detection of damage in materials

(57) A coating 2 that can be applied to a structure (1) to indicate damage to the structure that is otherwise not generally visible, includes a plurality of dye-loaded opaque capsules (3) which are designed to rupture when the structure is subject to a pressure greater than that liable to damage the structure. When ruptured, the capsules 3 release the dye which is readily visible. A fluorescent dye is preferably used.

The invention is especially suited to use with epoxy-based composite materials e.g. carbon fibre laminates which can be damaged and so lose their strength without the damage being visible to the naked eye. The coating, in the form of a paint may be used to indicate impact damage to an aircraft wing or a crash helmet and to indicate structural damage to a bridge.

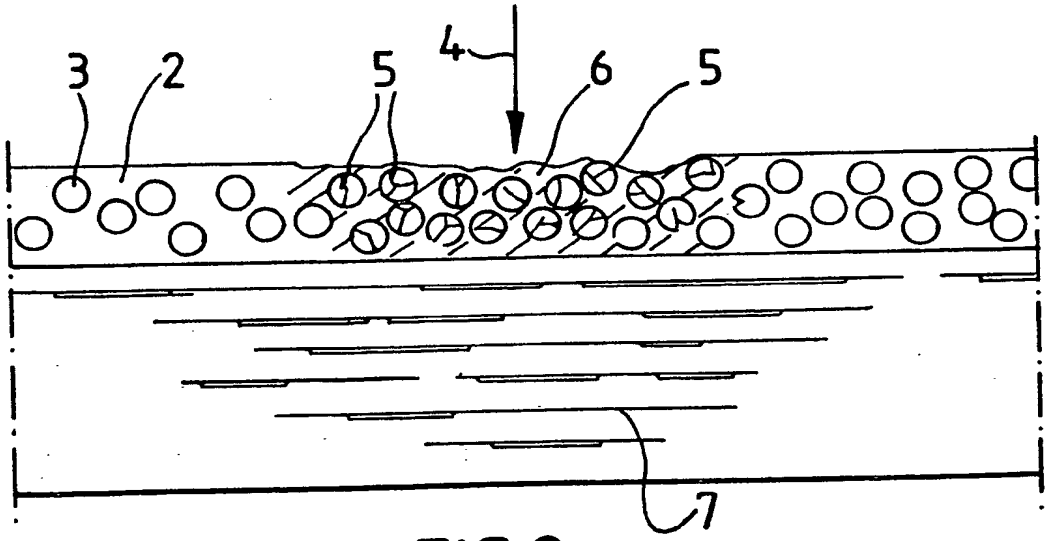

FIG.2.

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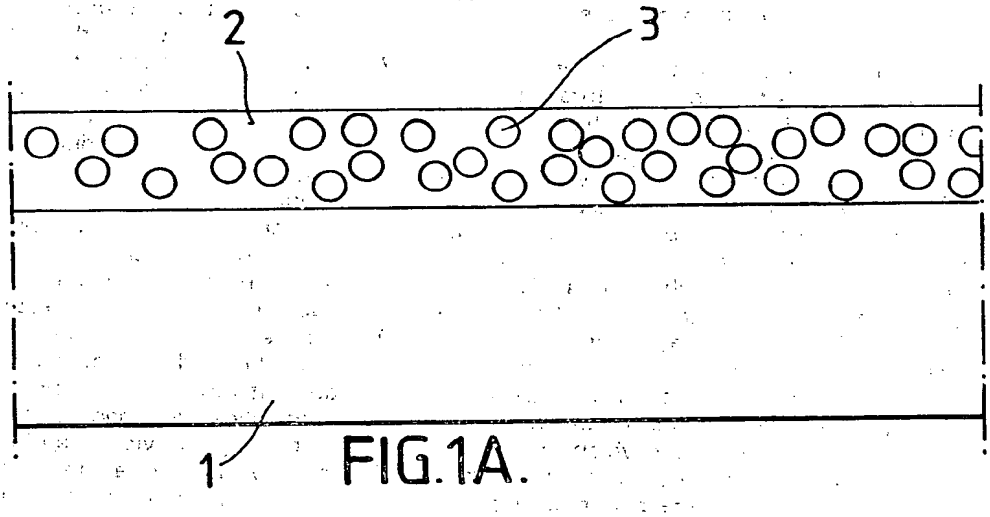

FIG.1A.

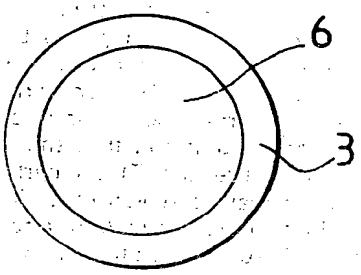

FIG.1B.

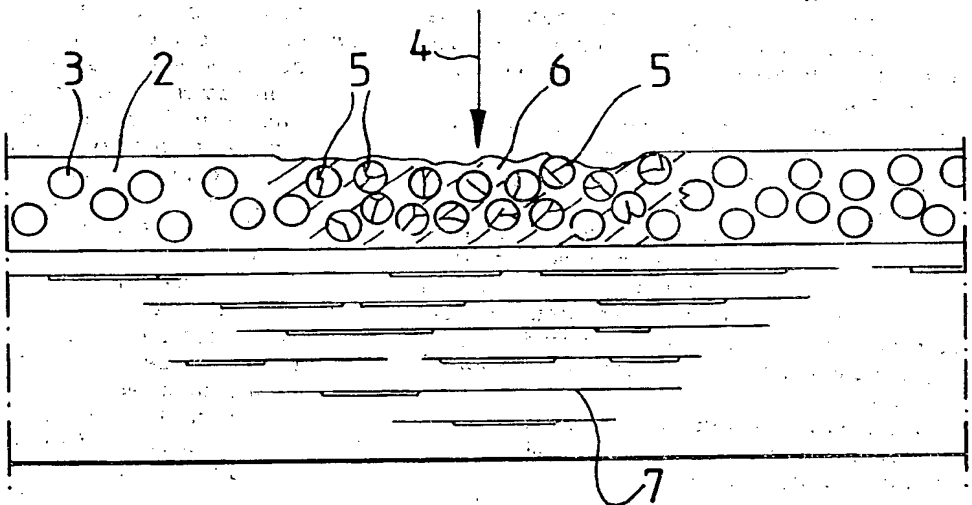

FIG.2.

SPECIFICATION

Detection of damage in materials

This invention relates to the detection of damage in materials, particularly structural materials and especially to the detection of damage, such as ballistic impact damage, in composite materials, for example epoxy based materials, e.g. carbon fibre composites.

It is established that the brittle behaviour of epoxy based material produces severe degradation of strength when subject to ballistic impact damage. In particular carbon fibre composites are known to display significant strength reduction even at levels of impact energy which do not produce an indentation on the impacted surface. This is due to brittle failure of the layers of epoxy which bind the individual plies together. The minimum energy at which the impact damage becomes apparent is termed the Barely Visible Impact Damage (BVID) level. The strength reduction at this level may be as high as 50% of the undamage laminate compressive value. As such damage is not readily apparent it is necessary to design carbon fibre composite structures under an assumption that the BVID level of damage is present. This clearly can lead to weight/penalties which may, in the case of certain produts particularly aircraft using such carbon fibre composites in their structure, be unacceptable.

At present the detection of levels of damage in a structure below the BVID level necessitates the inspection of the entire structure by non-destructive testing for example ultrasonic non-destructive testing. It will be appreciated that if the structure concerned is large, such as an aircraft wing or fuselage, this detailed complete inspection is extremely time consuming.

It is an object of the present invention to provide a method and material for indicating damage to structures due to impact or other damaging forces where the damage is not readily visible, e.g. it is below the BVID level. It is a further object of the invention to provide an automatic indication of such levels of damage and its location so that detailed non-destructive testing can be conducted by a simple local inspection to establish the need for repair.

Accordingly, the invention provides a structure comprising a material that is liable to structural damage when subject to a pressure greater than a known threshold value, the structure further including a surface layer incorporating a plurality of hollow capsules each loaded with a dye and wherein the dimension, shape and strength of the capsules are such that the capsules rupture when subject to a pressure that is substantially the same as or greater than the said threshold value but the capsules are not ruptured by a pressure substantially lower than the threshold value.

According to a further aspect of the present invention, there is provided a method of providing a structure with a capability of automatically indicating when it has been subject to a pressure above a threshold value at which the structure is liable to damage and of subsequently inspecting the same for said damage, which method comprises applying to visible surfaces of the structure a layer incorporating a plurality of capsules each loaded with a dye and the dimension, shape and strength of which capsules are such that the capsules rupture when subject to a pressure that is substantially the same as or greater than the said threshold value but the capsules are not ruptured by a pressure that is substantially lower than the threshold value and inspecting the visible surfaces periodically during the operational life of the structure for the effects of one or more of the capsules and release of dye therefrom.

British Patent Specification 1,313,058 describes a coating for indicating cracks in structural members; the coating includes dye-loaded capsules that are ruptured when the coating is fractured following a crack in the underlying structural member. However, such capsules rupture under pressures that are lower than those that would damage the structural members and therefore do not give an indication of impact damage to the structural member.

Preferably the capsules are small in comparison with the surface dimension of the structure to which they applied or form a part and are of an opaque material. The capsules may, however, be formed of a basic transparent material provided that they are substantially entirely coated with an opaque film or an opaque filler is added to the basic material during manufacture of the capsules. Carbon black is one example of an opaque filler material which may be added to a basic transparent material of the capsules during manufacture.

The capsules are preferably made of a material, e.g. glass or a polymeric material, that is brittle when subjected to a sufficient force. The capsules may be made by known encapsulation methods. The minimum pressure under which the capsules in a surface coating break can be set by varying the wall thickness of the capsules.

A metal film may advantageously be applied to the surfaces of the capsule because the capsules will then together provide an electrically conductive layer offering additional protection for EMC, EMP or Lightning Strike Protection on composite surfaces. The metal film may be applied to the capsules by any of the known metalising techniques. Embodiments of th invention will now be decribed by way of example only and with reference to the accompanying drawings of which:—

Figure 1 shows schematically an impact

damage indicator material applied to a structural material and in particular

Figure 1a shows a cross-section through an automatic impact damage indicating material, and

Figure 1b is an enlarged cross-section of a micro capsule used in the surface of the material of Fig. 1a, and

Figure 2 is a cross-section of the material of Fig. 1a after sustaining impact damage.

In Fig. 1 structural material 1, such as the carbon fibre composite material of an aircraft component e.g. a wing or fuselage, has been surface painted with a paint 2 incorporating a plurality of dye loaded micro capsules 3 shown in detail in Fig. 1b. Each micro capsule 3 is a micro sphere of an opaque material or a transparent basic material with an opaque additive such as carbon black or a transparent material coated with an opaque film such as a metal film and contains a fluorescent dye 6 for example fluorescein. One suitable commercially available dye developed for flaw detection may be PENETREX.

The wall thickness, the diameter and the material of the micro capsules 3 are chosen such that they will rupture on the application of a known magnitude of impact energy below the BVID level of the composite substrate 1. Such an impact whilst possibly causing delamination damage below the surface of the composite substrate 1 would not normally cause any visible surface damage to the material. However, as shown in Fig. 2 the impact force 4 is sufficient to break the micro capsules 5 in the surface layer of paint 2 and to release their fluorescent dye 6. The dye then provides a readily visible indication of possible sub-surface delamination damage 7.

Many modifications and improvement to the embodiment described above will be apparent to readers skilled in the art of material coatings and dyes. The term 'dye' in this specification means any material, usually in liquid form, which is visible to the human eye or an imaging device (e.g. a cameral) or can be made visible to the human eye or an imaging device by exposure to an appropriate radiation such as ultra violet radiation, or is a material capable of reacting with other materials, e.g. constituents or additives of the primer or paint in which the dye loaded capsules are suspended, to produce a material visible to or capable or being made visible to the human eye or an imaging device.

The present invention is applicable to any part or object that is liable to damage by impact or excessive forces; for example, the present invention is applicable to crash-helmets which are sometimes damaged structurally by being dropped and need to be replaced but the damage is not visible and so the owner is not aware that the helmet has been damaged; however, if the helmet were coated with a layer including dye-loaded capsules of the type described above which are designed to rupture under an impact that would damage the helmet, it would be apparent when the helmet needs to be renewed.

Another example of the application of the present invention is to detect an occurence of a structure, e.g. a bridge, being overloaded; thus, for example in the case of a a road bridge, part of the road surface could be coated with dye-loaded capsules that rupture when subject to a load that is greater than the load that the bridge was designed for. In this way it would be possible to detect that such a load, e.g. a heavy lorry, had passed over the bridge whose structure could then be inspected for damage.

The layer containing dye loaded capsules may be applied to a structure in the form of a paint or primer in which the capsules are dispersed in a vehicle (i.e. a binder and a solvent) of customary type used commercially in paints.

In the following claims, the dye loaded capsules are stated to rupture at certain applied "pressures", but in some technologies, it is more usual to refer to damage being caused by a force having a certain impact energy rather than to damage being caused by a pressure. However, it will be appreciated that it is the magnitude of pressure that a force exerts that causes the damage and not the magnitude of the force itself and it is for that reason that the following claims refer to pressures rather than to forces, but the two parameters are of course inter-related by the area over which the force is applied.

CLAIMS

1. A structure comprising a material that is liable to structural damage when subject to a pressure greater than a known threshold value, the structure further including a surface layer incorporating a plurality of hollow capsules each loaded with a dye and wherein the dimension, shape and strength of the capsules are such that the capsules rupture when subject to a pressure that is substantially the same as or greater than the said threshold value but the capsules are not ruptured by a pressure substantially lower than the threshold value.

2. A structure as claimed in claim 1, wherein the material is a fibre-reinforced composite material.

3. A structure as claimed in claim 2, wherein the fibre-reinforced material incorporates carbon or glass fibres.

4. A structure as claimed in claim 2 or claim 3, wherein the fibre-reinforced material includes an epoxy resin binder.

5. A structure as claimed in any one of claims 1 to 4, wherein the capsules have walls that are brittle and so shatter when subject to a pressure that is substantially the same as or greater than the said threshold

value.

6. A structure as claimed in claim 5, wherein the capsule walls are made of glass or a polymeric material.

7. A structure as claimed in any one of claims 1 to 6, wherein the dye is fluorescent, e.g. fluorescein.

8. A structure as claimed in any one of claims 1 to 7, wherein the wall of each capsule is opaque.

9. A structure as claimed in any one of claims 1 to 7, wherein each capsule is coated with a conductive material, e.g. with a metal film.

10. A method of providing a structure with a capability of automatically indicating when it has been subject to a pressure above a threshold value at which the structure is liable to damage and of subsequently inspecting the same for said damage, which method comprises applying to visible surfaces of the structure a layer incorporating a plurality of capsules each loaded with a dye and the dimension, shape and strength of which capsules are such that the capsules rupture when subject to a pressure that is substantially the same as or greater than the said threshold value but the capsules are not ruptured by a pressure that is substantially lower than the threshold value and inspecting the visible surfaces periodically during the operational life of the structure for the effects of the rupture of one or more of the capsules and release of the dye therefrom.

11. A method as claimed in claim 10, wherein the material is a fibre-reinforced composite material.

12. A method as claimed in claim 11, wherein the fibre-reinforced material incorporates carbon or glass fibres.

13. A method as claimed in claim 11 or claim 12 wherein the fibre-reinforced material includes an epoxy resin binder.

14. A method as claimed in any one of claims 10 to 13, wherein the capsules have walls that are brittle and so shatter when subject to a pressure that is substantially the same as or greater than the said threshold value.

15. A method as claimed in claim 14, wherein the capsule walls are made of glass or a polymeric material.

16. A method as claimed in any one of claims 10 to 15, wherein the dye is fluorescent, e.g. fluorescein.

17. A method as claimed in any one of claims 10 to 16, wherein the wall of each capsule is opaque.

18. A method as claimed in any one of claims 10 to 17, wherein each capsule is coated with a conductive material, e.g. with a metal film.

19. A structure substantially as hereinbefore described with reference to and as illustrated in Fig. 1 or Fig. 2 of the accompanying drawings.

20. A method as claimed in claim 10, substantially as hereinbefore described with reference to Fig. 1 or Fig. 2 of the accompanying drawings.

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